Grade 4 STEM DESIGN CHALLENGE
CORRESPONDING ENGINEERING DESIGN PROCESS STAGE IN RED

Unit 2: Investigating Force and Motion
Topic: Design a Bridge to Withstand Forces
Subject/ Grade level: STEM/ Grade 4

Materials:
For each student group of 2 or 3:
- Design logs
- Rope
- Scales
- Foam Pieces (12" long x ~2.5" wide, 2 per group (1 for constructing prototype , 1 for redesign)
- Dowels, 12" long 3/16" diameter
- String 16" long
- Two piece dowel ~1.5" long to apply the tension to the string
- Bucket and small cup
- Large amount of sand
- Rulers, pencils, scissors
- Lego plates from Lego kits
- 2 parallel planes (e.g., equally thick books, lying flat with 2 inches of overlap on each side)
- Various building materials (teacher discretion) for student bridge designs, if desired (e.g., additional string, scissors, cardboard, etc.)
- Handouts
  - "Bridges Y-Chart"
  - "Bridges Report"
  - 21st Century Skills rubric to grade the project
- Websites
  - http://science.howstuffworks.com/engineering/civil/bridge7.htm
  - http://www.pbs.org/wgbh/nova/tech/build-bridge-p4.html
  - http://www.google.com/search?q=bridges&safe=active&es_sm=93&source=lnms&tbm=isch&sa=X&ei=aACBU6PQJo2zsASj_YHoCA&ved=0CAgQ_AUoAQ&biw=1746&bih=890
  - https://www.brainpop.com/technology/scienceandindustry/bridges/

TEKS
Science
*SCI.4.6D Design an experiment to test the effect of force on an object such as a push or a pull, gravity, friction, or magnetism.
Ⓟⓢ SCI.4.2B Collect and record data by observing and measuring, using the metric system, and using descriptive words and numerals such as labeled drawings, writing, and concept maps.

Math
Ⓟⓢ 4.1A Apply mathematics to problems arising in everyday life, society, and the workplace.
Ⓡ MATH 4.11A Estimate and use measurement tools to determine length (including perimeter), area, capacity, and weight/mass using standard units SI (metric) and customary. (Pre-Teach, Cycle 3)

ELPS
C3D Speak using grade-level content area vocabulary in context to internalize new English words and build academic language proficiency.
C5B Write using newly acquired basic vocabulary and content-based, grade level vocabulary.

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CCRS

Science

5E1A Create a model of a system and use that model to predict the behavior of a larger system.

8C2A State Newton's Laws of Motion to demonstrate understanding of their application through lab activities.

Math

3A2F Apply properties of geometric figures to solve problems.

8C1C Interpret results of the mathematical problem in terms of the original real world situation.

Cross-Disciplinary

1C1B Break complex problems into component parts that can be analyzed and solved separately.

1E2C Work in small groups to investigate a problem or conduct an experiment.

Lesson objective(s):

The students will apply concepts of pushes and pulls to the design of a model bridge.

Differentiation strategies to meet diverse learner needs:

In the Identify the Need stage, a Google picture search is suggested to help students visualize different bridge types.
In the Research the Problem stage, a PBS online bridge game is suggested to help students review new knowledge.
In the Select the Most Promising Solution stage, a graphic is provided to help students visualize areas of pushing and pulling in their designs.
In the Redesign stage, suggestions are provided to help students make adaptations to their bridges.

IDENTIFY THE NEED

Begin by asking students, *"What makes an ideal bridge?"*
Allow students 2-3 minutes to discuss in pairs what would make an "ideal" bridge. List the responses on the board.

Differentiation:

For students who are not as familiar with different bridge forms, conduct a Google image search or show them the following link so they can view many models at once: http://www.google.com/search?q=bridges&safe=active&es_sm=93&source=lnms&tbm=isch&sa=X&ei=aACBU6PQJo2zsASj_YHoCA&ved=0CAgQ_AUoAQ&biw=1746&bih=890

Ask for two student volunteers. Have the students hold on to opposites sides of a rope (or a slinky). Have each student tug on their end of the rope (tug of war-like) to simulate tension, *or pull force*. Have the students *then push the ends together* to simulate compression force.

Share with the students that all bridge building materials undergo forces, like push and pull, which they must withstand to function as designed. Concrete, a material used to make the **deck** of a bridge, or the part that cars drive over, is strong under forces that push on it, but does not withstand being pulled and can crack if forced to do so. For this reason, when used for bridge building, concrete contains steel bars (called **rebar**) to improve its performance. (See rebar photo to the right.)

Explain the design task to students as follows:

"Your challenge is to design a model bridge that can carry the most sand and determine the strength of your bridge. Using the items provided, and foam to represent concrete, you will test your bridge to its point of failure to determine its strength."

Analogy
Have students stand up and bend over at the waist, keeping their knees straight. "Feel your back stretch, and feel the folds in your belly." Ask students in what part of their bodies do they feel a pull? (back, behind knees)
Then ask them where they feel a push?(belly, feet into ground)

Extension:
Have students write an analogy, such as: *"When doing a forward bend, a pull is to my _______ (back/knees) as a push is to my _______ (belly/feet)."*

Teacher Background Information:
In order to understand how forces affect concrete, students must first understand that forces affect objects differently. In the actual concrete deck of a bridge, there are parts of the concrete under tension (being pulled) and parts under compression (being pushed). Concrete does not withstand high forces of tension (pulling). Therefore reinforcement must be added. In the redesign section of this challenge, students will design to allow the deck of their bridge to withstand a larger force, and if done correctly, carry more weight.

Formative Assessment:
In teams, have students discuss the design problem and then write it in their own words in their design logs. An example writing prompt could be, *"Explain the design problem in your own words."*

RESEARCH THE PROBLEM

Show students the BrainPop movie, "Bridges" to learn about the different types.
Link: https://www.brainpop.com/technology/scienceandindustry/bridges/

Review with students, by asking the following questions after the movie:
"What is a force?" (In its simplest form, it is any push of a pull.)
"What are the 3 forces discussed in the BrainPop movie and what do they do?" (Tension pulls things apart, Compression pushes them together, and gravity pulls things toward the Earth's center.)

Differentiation:
Students can test their new bridge knowledge further online via the "Build a Bridge" PBS matchup game found here: http://www.pbs.org/wgbh/nova/tech/build-bridge-p4.html

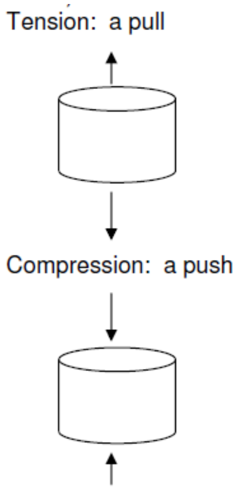
(**Teacher Note**: A new type of bridge, called a cable-stayed bridge, is introduced in the PBS game. Quick info. on this type is here: http://science.howstuffworks.com/engineering/civil/bridge7.htm)

Formative assessment:
Have students complete the "Bridges Y-Chart" handout to review the advantages and disadvantages of each of the 3 basic bridge designs, as learned through the movie.

Extension:
Have students with extra time or the interest research and complete a report on an important bridge in the city or state using the "Bridges Report" handout.

DEVELOP POSSIBLE SOLUTIONS

For a review, draw the following on the board and have students record the diagrams in their design logs:



Based on the drawing, ask students the following questions:

1. *"Which of our materials that you have to build with will we use to represent the pushing, or compression, of a bridge?"* (Students may recall foam.)
2. *"Which of our materials that we have might we use to represent the pulling or tension of a bridge?"* (Students may be able to predict string or the long dowels.)

3. *Why do we care about push and pull when building a concrete bridge? (*After student explanations, share that engineers need to know how much weight their concrete can hold before they can build a bridge. Instead of building a bridge and testing how many cars can go across it, then making it stronger next time, they mix a test section, shaped like the cylinders pictured in our drawings, using the type of concrete they plan to use. Then they crush these cylinders to test its strength.)

Differentiation:
Before the students begin their designs, make sure they understand the key concepts so far. Have them turn and talk to a neighbor about the following:
1. Compression (the pushing force acting on a bridge)
2. Tension (the pulling force acting on the bridge)
3. What the "deck" of a bridge refers to (where the cars drive over)

Formative Assessment:
Before students begin the actual construction of their bridges, team members will sketch two ideas for the deck of their foam bridge in their design logs using their research so far and the materials available.

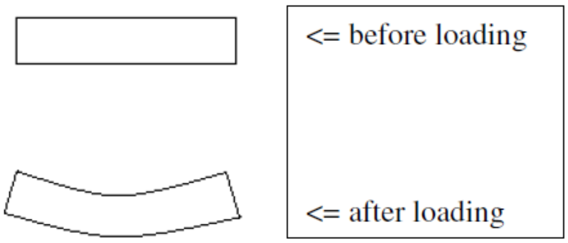
Extension:
Tell students, *"An object, much like the deck of your bridge, can have different parts in compression (pushed upon) and tension (pulled upon). In your design sketches, label which portion is in compression (being pushed) and which is in tension (being pulled). "*

SELECT THE MOST PROMISING SOLUTION

Based on their design sketches, teams will discuss and decide which one is the best and WHY. Out of the choices, they will select their final design to build for the "Construct a Prototype" stage.

Formative Assessment:

Each member should indicate in writing in their design log which of the designs was chosen by the team, and WHY.
Differentiation:
Students that struggle with making a final decision in this stage may need to first think about when they touched their toes, and where the pushing and pulling occurred, to decide which sketched design they predict will best deal these two forces.



CONSTRUCT A PROTOTYPE

(**Teacher Note:** The amount of design that you let the teams do is up to you. When they are ready to add the sand load to the bridge, note that teams do not need to test to complete failure, or when the foam snaps. However, they should know that when beams are tested by engineers in real life, they are still tested to when the concrete is crushed. To do this, each phase of failure is documented. With concrete, engineers document the level of cracking and its progression. This is similar to noting when students' foam begins to bend and crack.)

Teams will then use the time allotted for this stage to build their final design. This final design is the one the team will use for testing in the next stage.

Formative Assessment (in design log):
As a separate entry in their design logs, teams should tell how they made their bridge (the directions) and any problems they experienced when building.

TEST AND EVALUATE PROTOTYPE

Once teams have their final design built, it will be tested to see how much of a load it can bear. Students should bring their decks to the designated testing area (an area you will decide). When teams are instructed to test, they will place a bucket on the deck and fill that bucket with sand until the deck "fails," or bends/cracks. Once there is failure, teams will weigh the bucket to see how much force it was able to withstand.

To load the deck, teams will need to:

1. Set up the deck between two level planes with approximately two inches on each side as overlap, leaving about eight inches clear in the middle.
2. Next, place a small flat object in the center (a Lego plate works well). This allows the load to be distributed along a distance.
3. Then place the bucket so that it is in the center of the foam and the "load distributor" (Lego plate) and is hanging freely below.
4. Begin to add sand to the bucket. Remember that sand is loaded until the foam starts to bend/crack.
5. One of the students in the team should keep their hands near/around the bucket so that when the deck fails, the student can catch the bucket and the sand stays in it for weighing purposes.
6. Lastly, teams will weigh the bucket and record its weight in their design logs.

Formative Assessment:
Have students copy and then work in their teams to answer the following questions in their design logs:

1. How much sand did your bridge hold?
2. What about your design works well?
3. What about your design could be improved?
4. What advice would you give to next year's class on how best to build a foam bridge?

COMMUNICATE THEIR DESIGN

During the conclusion of this activity the class should compare the forces withstood by each team's respective designs and their effects. This is an important discussion. The teacher should display the data from all teams together prominently (in a table on the board) and use it to drive the discussion.

Formative Assessment (in design logs):
The student audience should evaluate the designs after all demonstrations are complete on the following criteria in their design logs:
1. Which teams' design worked the best?
2. How much sand did it carry?
3. What about the design allowed it to carry the most sand?

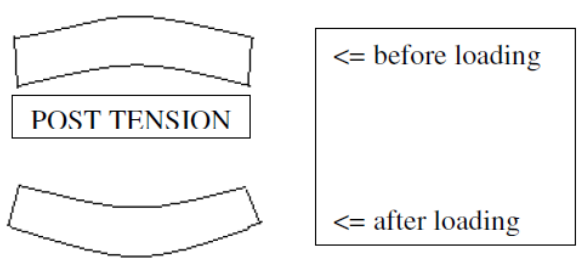
REDESIGN

For the redesign stage, students will use the string and/or the dowels to reinforce their bridge in a way that helps to address the pulling forces (tension) of the bridge.

Differentiation:
You might help struggling students by suggesting that teams place the reinforcement either taped to the outside or they can create a 'gouge' by scoring the bottom of the foam and placing the dowel or string in the length of the crevice. (**Teacher Note:** This would be more similar to actual bridges where reinforcement is placed in the lower half of the deck.)

Formative Assessment (in design logs):
As a summative task, have students test their redesigned bridge to see if it can hold more sand before "failure" (as you defined it throughout). Again, the push force (weight) of the sand should be recorded on the board in a class table and in student design logs. In design logs, students should also explain about 1) the force the string/dowel helped the bridge to withstand, and 2) how it works to do this.

Extension:
Have students experiment with the technique called **post-tensioning** in their design. This allows for a larger load to be placed over the deck. (**Teacher Note:** This works best in a 'gouge' or inset in the TOP portion of the deck. Use the small dowels to hold and tighten the string to apply the tensile force to bow the deck upwards. See the illustration here. It will still fail the same way as with the dowel/string version, but could hold a heavier load. A similar example that uses post-tensioning can be seen in the trailer of flatbed semi-trucks. If you look at one without a load on it, it bows upward so it will not sag as much or at all once weight is added to it.)



MATH CONNECTION

Discussion of Stress

Does the strength of a small section of the bridge equal the strength of the entire length of the bridge? No. To compute this, engineers divide the force by the cross-sectional area. This is called the **stress** of the deck.

Stress = force (lbs.)/ area (in.^{2})

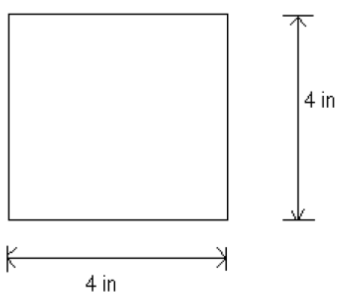
Give the following example to students. Show them 2 shoes, one with a large flat heel (e.g., a tennis shoe) and another with a small, spiky heel. Ask them, *"If a person were to stand in each shoe, will the force he/she puts on the floor be different?"* (No, it will be the same because I weigh the same in both shoes).
"Will the stress be different?" (Yes, since the cross sectional area of the spike heel is so much smaller, the stress will be much greater. This is why women can poke holes in soft floors with their heels!)

Formative Assessment:

Review with students how to calculate the area of a square. (Count up square units if a grid is imposed, or length x width). Then, have students complete the following example.

Directions: "*Calculate the area and stress for the following shape. Assume there is a 20 pound compression (push) force applied to the shape. Show your work.*"

What is the stress of a deck of these dimensions?



Area _______________ in.^{2}

Stress _____________ psi

Extension:

Have teams calculate the stress of their decks and record this information in their design logs. (Answer will vary.)

Stress= force (weight of sand) / area (of their deck).